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REVIEW ON SOLID STATE WELDING

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ABSTRACT

The study explores the innovative friction-assisted solid-state lap seam welding method, showcasing its success in creating multi-metal, multi-layered friction seam welds with diverse materials. Metallurgical bonding achieved through dynamic recrystallization at the seam weld interface resulted in enhanced tensile strength compared to base metals. The research emphasizes the method's applicability in the aeronautic industry, addressing challenges in joining advanced materials. The environmental advantages of Friction Stir Welding (FSW) over conventional arc welding are highlighted, offering valuable insights into its superior mechanical properties. The findings suggest promising avenues for advancing welding techniques, urging further research for refining metallurgical bonding mechanisms and optimizing process parameters for diverse material combinations.

Keywords: Friction Stir Welding (FSW), solid-state lap seam welding, solid-state bonding

I. INTRODUCTION

Welding techniques have been essential in defining industrial manufacturing in the field of metal joining. Since the middle of the 19th century, traditional techniques like arc and gas welding have been used, but they have drawbacks like distortion, heat-affected zones, and problems with reactive metals like magnesium and aluminium. Friction stir welding (FSW) [1-3], which was developed in 1991 to address these issues by preventing melting, revolutionized the welding process. Without using consumable materials, FSW creates joins at temperatures below melting points using a spinning tool [4]. It is excellent at welding magnesium and aluminum alloys, producing joints free of flaws, better qualities, and time and money savings. FSW creates various, individually distinct microstructural areas in the weld [5]. To fully utilize FSW, several factors like material composition, machine settings, and tool design must be carefully taken into account [6].

II. METHODOLOGY AND MATERIALS:

The steps involved in the friction stir welding processes are discussed in the following sections.

Materials:

For FSW of aluminum alloys, reported study says that Rolled plates of aluminum alloy (AA) 6061 with a 4 mm thickness were machined to meet the required dimensions of 150 mm x 60 mm. Additionally, various metallic sheets were also employed, including AISI 304, AISI 1012, Ni-based alloys such as IN 600, IN 625, HX, commercially pure (CP) Cu, CP Ni, and Ti6Al4V. The metallic sheets had a thickness range from 0.5 to 5.0 mm, standardized at 190 mm × 200 mm × thickness. Non-consumable rods played a crucial role in seam welding, particularly CP Mo rods with 25.4 mm diameter and AISI 304 rods with 25.4 mm diameter and Ra 1–2 μm [3]. A CP-Mo rod was used for high-temperature melting of metal sheets, and an AISI 304 rod was used for low-temperature melting of metal sheets was employed. In addition to these materials, the experiments also included the use of a 1.5 mm thick aluminum alloy EN AW 5005 machined to a length of 100 mm and a width of 25 mm, with the samples overlapping in an area of 25 mm × 25 mm [5].

Preparation of materials:

Two different welding processes was used to prepare the materials. The first method was TIG welding to fabricate butt joints using filler metal AlSi5 and argon as a protective gas. This process specifies precise welding parameters such as current, voltage, welding wire diameter, welding speed, and gas flow rate. In the second method, using friction stir welding (FSW), created a butt joint by joining two plates with a rotating tool assembly [7]. The tool is made of tool steel hardened to 60 HRC, has specific dimensions, and rotates counterclockwise at 1000 rpm, facilitating the welding process on a CNC milling machine. For EN AW 5005 aluminum alloys, weld samples was tested on an INSTRON 8801 tensile tester using lap shear samples of specific dimensions to evaluate shear strength under various welding conditions. did. In

the case of annealed AA1050 aluminum strips, samples with trapezoidal cross sections were subjected to elongation and compression in a tensile testing machine during material preparation. This process used heated flat tools driven together by a hydraulic flat piston to prevent out-of-plane buckling during compression [8]. A Teflon-filled lubricant reservoir was integrated to minimize friction between the tool and the sample. Additionally, narrow slits with a width of 1 mm were strategically cut at 15 mm intervals on the opposite side of the glued sample. These slots ensure that shear forces are generated in room temperature shear tests that ultimately lead to the failure of the weld.

Tool shape and welding equipment:

Different welding methods use different tools. In single-lane seam welding, the top metal sheet is placed on top of the bottom metal sheet and pressed against the anvil. A rotating non-consumable rod (CP Mo or AISI 304) moved toward the top sheet, generating frictional heat and plasticizing a portion of the top metal sheet. The relative motion between the metal stack and the fixed non-consumable rod formed a metallurgical bond. In multilane seam welding, these steps were repeated after axial displacement of the clamped laminated core. Detailed welding process parameters are available. TIG welding used specific parameters and welding wire for butt welding. The friction stir welding (FSW) was a rotating tool assembly with a tool steel tool driven by a CNC milling machine with an 11 KW motor [9]. Tool specifications include shoulder diameter, top pin diameter, bottom pin diameter, and pin height. Two welding processes were used in the EN AW 5005 aluminum alloy welding equipment [10]. For resistance spot welding, a water-cooled copper electrode with a contact diameter of 4 mm was used in a resistance spot welding machine, with parameters ranging from 5 kA to 50 kA based on literature recommendations. Friction stir spot welding (FSSW) of this alloy was performed on a CNC vertical milling machine using AISI 1050 steel as the tooling material and using specific parameters [11]. AA1050 aluminum strip used a heated flat die driven by a hydraulic flat ram for vertical compression. The welding equipment was a tensile testing machine for performing shear tests at room temperature.

Hardness measurement: Hardness measurements included Vickers hardness profiling of the weld using a microhardness meter, provides insight into the hardness characteristics of the weld. To complement the hardness evaluation, further analysis of the fracture surfaces of the weld samples has to be performed using scanning electron microscopy [12]. Additionally, tensile tests are to be performed on samples manufactured according to the EN 895:1995 standard using a computer-controlled tensiometer at a constant crosshead speed of 5 mm/min. Additional hardness measurement details beyond microhardness testing of aluminum alloys EN AW 5005 or adjacent AA1050 materials were not explicitly listed [13-15]. Comprehensive information on other hardness measurement methods or specific details for the materials listed may require additional data or references beyond what is provided.

III. RESULTS AND DISCUSSION.

The study introduces a novel friction-assisted solid-state lap seam welding method, demonstrating its success in fabricating multi-metal, multi-layered friction seam welds using various materials, including AISI 304, AISI 1012, Ni-based alloys, CP Cu, CP Ni, Ti6Al4V, and AA6061. Metallurgical bonding achieved through dynamic recrystallization at the seam weld interface resulted in higher tensile strength compared to base metals. The application of this method in the aeronautic industry, particularly in diffusion welding and friction welding, is highlighted, addressing challenges in joining advanced materials. Additionally, the research explores the potential of rotational friction welding in ultrafine grain copper welding, emphasizing the need for careful consideration of process parameters. The study concludes by underscoring the environmental advantages of Friction Stir Welding (FSW) over conventional arc welding and provides valuable insights into FSW's applications across diverse materials, including its superior mechanical properties in joints compared to traditional welding methods. The findings suggest promising avenues for advancing welding techniques and encourage further research to refine metallurgical bonding mechanisms and optimize process parameters for various material combinations.

Appropriate handling of reactants: The experimental findings show that process temperature has a major impact on bond strength, with process duration having a minor effect. Diffusion mechanisms are taken into account and Fick's first law is used to interpret the patterns that have been noticed. The mobility of aluminum atoms is described by the diffusion coefficient (D), which can be thought of as an Arrhenius-type relationship. The diffusion mechanism affects D0, the diffusivity constant. It is suggested that the natural logarithm of bond shear strength and the inverse of process temperature have a linear connection in a diffusion-

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controlled process. This theory is supported by experimental evidence, which points to a diffusion-controlled process. Diffusion distance is related to time using Fick's second law, which implies a proportionate relationship between bond strength and the square root of process time. The experimental data, on the other hand, demonstrates that different correlations cannot be attributed to diffusion alone in explaining all the features of solid-state bonding.

Environmental control: The intricacy of solid-state bonding processes is highlighted by the analysis of diffusion mechanisms and their effect on bond strength. According to the findings, quick bonding techniques like cold roll bonding can produce good bindings at lower temperatures even with little diffusional transport. Diffusion processes become increasingly noticeable as the process temperature rises. Since aluminum and its oxide are insoluble in one another, diffusion probably improves substrate contact between islands of fractured oxide. This realization is important for environmental control because it suggests that diffusion mechanisms become more important in the bonding process at higher temperatures.

Quality control: Since the relationship between bond strength and temperature may be described as a diffusion-controlled process, optimizing the diffusion processes should be the primary goal of quality control techniques. The trends show that diffusion becomes more significant at higher temperatures, while other mechanisms, such as film theory, may predominate at lower temperatures. By adjusting process variables, especially temperature and time, quality control techniques should take these temperature-dependent changes into account and work toward consistently achieving the desired bond strengths.

Safety measure: The results of the experiment highlight the need to take diffusion mechanisms into account when implementing safety precautions. Understanding diffusion's involvement is essential for guaranteeing safety as different bonding mechanisms occur at different temperatures. Owing to greater diffusion mechanisms, processes using higher temperatures may provide distinct safety difficulties. As a result, safety precautions should be customized to the unique features of the bonding process, keeping in mind variables linked to temperature and any changes in diffusion behaviour.

The microhardness distribution showed softening and lower hardness for TIG, in contrast to higher hardness for FSW due to shear stress and fine particles. The tensile properties of the connection were worse than those of the base metal, and the FSW had higher ductility [16]. A comparison between RSW and FSSW demonstrated a clear superiority of FSSW in lap shear strength due to microstructure refinement, with an improvement of 304% over RSW due to improved hardness distribution [17]. Visual inspection identified gaps and cracks related to material flow, especially in his FSW. The operating parameters of FSW have a significant influence on the mechanical and visual properties, highlighting their central role. During diffusion welding, after 180 min at 500 °C, a complete diffusion zone with visible intermetallic compounds was formed [18]. This study provided a comprehensive insight into the complex interactions and material behavior during different welding processes [19]. Furthermore, experimental shear tests of solid welds showed significant differences in weld strength with respect to process temperature and time, highlighting the role of temperature and time on joint strength. Diffusion mechanisms appear to be in play, with lower temperatures minimizing diffusive transport to obtain sufficient bonding, and higher temperatures enhancing the diffusion mechanisms, allowing the substrate to flow between oxide islands. We were unable to fully account for the bonding properties due to the possibility of increased contact [20]. This suggests that both diffusion and membrane theory mechanisms contribute to the binding process, as shown in our study results. Joining of titanium with stainless steel with copper as interlayer reduced the intermetallic and improved the joint efficiency [21]. Of all the welding parameters tool pin profile was found to be an important factor in the process [22].

IV. CONCLUSION

Investigation of welding techniques revealed distinctive macrostructural features in TIG and FSW connections.

The particles of the base metal were coarse and elongated, and the precipitates were dispersed, which contributed to the improvement in strength.

The FSW compound exhibited fine equiaxed grains and exhibited dynamic recrystallization. On the other hand, the TIG compound showed a dendritic structure in the melting region.

REFERENCES:

[1] Prasad Rao Kalvala, Friction assisted solid state lap seam welding and additive manufacturing method, Defence Technology 12(2016)16-24

[2] Paul Kaha, Trends in Joining Dissimilar Metals by Welding, Applied Mechanics and Materials Vol. 440 (2014) 269-276

[3]. Ratnesh K. Shukla, Comparative study of friction stir welding and tungsten inert gas welding process, published by Indian Journal of Science and Technology, 3(2010)667-671

[4] Esther T. Akinlabi, Friction Stir Welding Process: A Green Technology, World Academy of Science, Engineering and Technology, 71(2012) 331 – 339.

[5]. A M Khourshid, Friction Stir Welding Study on Aluminum pipe, International Journal of Mechanical Engineering and Robotics Research, 2(2013), 710 – 724.

[6].S.Rajakumar, Establishing relationships between mechanical properties of aluminium alloys and optimised friction stir welding process parameters , Materials and Design, (2012) 17–35

[7]. G. H. Payganeh, Effects of friction stir welding process parameters on appearance and strength of polypropylene composite welds, International Journal of the Physical Sciences 6(2011), 4595-4601

[8]. Verma,A Critical Review Of Friction Stir Welding Process, Daaam International Scientific Book(2015)249-266

[9]. Jean Pierre Bergmann, Solid-state welding of aluminum to copper—case studies, International Institute of Welding (2013) 541–550

[10]. Mustafa Kemal Kulekci, Experimental Comparison of Resistance Spot Welding and Friction-Stir Spot Welding Processes for The En Aw 5005 Aluminum Alloy, 45(2011) 275-279

[11]. Jiaxin Lv, Analysis of solid-state welding in extruding wide aluminium hollow profiles using a new three-container extrusion system, Journal of Manufacturing Processes 94 (2023) 146–158

[12]. M Bevilacqua1, Comparison among the environmental impact of solid state and fusion welding processes in joining an aluminium alloy, Journal of Engineering Manufacture, 234(2020) 140–156

[13]. Mandeep Singh Sidhu, Friction Stir Welding – Process and its Variables, International Journal of Emerging Technology and Advanced Engineering, (2012) 1536 – 1538.

[14]. Vijay Sustainability of Fusion and Solid-State Welding Process in the Era of Industry 4.0, Handbook of Smart Materials, Technologies, and Devices(2022)1637–1654

[15]. Virendra Pratap Singha, Recent research progress in solid state friction-stir welding of aluminium–magnesium alloys, Journal of Material research and Technology, 9(2020)6217-6256

[16]. Balu Mahandiran, Investigation of Solid State Welding of Copper Nickel Alloy (Cu- Ni 90/10) Using FSW Process, Material Science and Engineering, IOP Conference,1145 (2021) 012112

[17]. Daniel R. Cooper, Influence of diffusion mechanisms in aluminium solid-state welding processes, Published by Elsevier Ltd. 2012 2147 – 2152

[18]. Z.W. Wang,Welding behavior of an ultrahigh-strength quenching and partitioning steel by fusion and solid-state welding methods, Journal of material research and technology 17(2022)1289-1301

[19]. Łukasz Morawiński1, Solid-state welding of ultrafine grained copper rods,Archives of Civil and Mechanical Engineering (2021) 21-89

[20]. Enes Akca, Solid State Welding and Application in Aeronautical dustry, Periodicals of Engineering and Natural Sciences, 4(2016).

[21] M. Balasubramanian, S. Murali, C. Hemadri, R. Kumar, A new method of dissimilar friction welding of titanium to stainless steel, Materials Today: Proceedings, 46(2021)3644-3647

[22] K. Elangovan, V. Balasubramanian, S. Babu, M. Balasubramanian, Optimising Friction Stir Welding parameters to maximise tensile strength of AA6061 aluminium alloy joints, International Journal of Manufacturing Research, 3(2008) 321-334.